U.S. NUCLEAR REGULATORY COMMISSION

STANDARD REVIEW PLAN

15.9 BOILING WATER REACTOR STABILITY

REVIEW RESPONSIBILITIES

Primary - Organization responsible for review of reactor thermal-hydraulic systems in BWRs

Secondary - None

I. AREAS OF REVIEW

The specific areas of review are as follow:

1. Coupled neutronic-thermal-hydraulic instabilities, also known as density-wave instabilities, are safety concerns for boiling water reactors (BWRs). Three recognized modes of density-wave instability are core-wide (when the power and flow of all the core channels oscillate in phase), regional (when the power and flow of half the core channels oscillate out-of-phase with the other half), and single-channel flow instability (when the flow in a single channel oscillates accompanied by small power oscillations).

2. Instability modes other than density-wave type are possible in reactors and their systems. The most common sources of unstable power oscillations are poorly-tuned control systems or control oscillations caused by partial failures like sticky valves. Other sources of unstable power oscillations are design-dependent. For example, passive natural-circulation reactors may be susceptible to oscillations or loop instabilities during the startup phase.

3. Certain instability events can lead to unacceptable consequences to the fuel if the reactor is not shut down on time. Specifically, for the density-wave regional stability mode, the original reactor protection system could not guarantee a timely shutdown because the average power range monitor signal averages the positive and negative sides of the power oscillation. Thus, the oscillation amplitude sensed by the average power range monitor is significantly smaller than the actual power oscillation experienced by the channels. Methodologies for resolving BWR core-stability issues presented in General Electric topical report NEDO-31960 and Supplement 1 (References 3 and 4) were approved by the NRC in Reference 2. These reports provide long-term solutions (LTSs) to BWR stability issues and present methods to support plant system designs that comply with General Design Criteria (GDCs) 10 and 12.

4. COL Action Items and Certification Requirements and Restrictions. For a DC application, the review will also address COL action items and requirements and restrictions (e.g., interface requirements and site parameters).

   For a COL application referencing a DC, a COL applicant must address COL action items (referred to as COL license information in certain DCs) included in the referenced DC. Additionally, a COL applicant must address requirements and restrictions (e.g., interface requirements and site parameters) included in the referenced DC.

Review Interfaces

Other SRP sections interface with this section as follows:

1. Sections 7.0-A and 7.2: determination of the adequacy of the hardware implementation of stability LTS.

2. For COL reviews of operational programs, the review of the applicant's implementation plan is performed under SRP Section 13.4, "Operational Review."

3. Section 15.8: determination of stability during anticipated transients without scram events.

The specific acceptance criteria and review procedures are contained in the referenced SRP sections.

II. ACCEPTANCE CRITERIA

Requirements

Acceptance criteria are based on meeting the relevant requirements of the following Commission regulations:

1. GDC 10, "Reactor Design," requires that specified acceptable fuel design limits (SAFDL) not be exceeded during any condition of normal operation, including conditions that result in unstable power oscillations with the scram system available.

2. GDC 12, “Suppression of Reactor Power Oscillations,” requires that oscillations be either not possible or reliably and readily detected and suppressed.

3. GDC 13, “Instrumentation and Control,” includes requirements for the hardware implementation of stability LTS.

4. GDC 20, “Protection System Functions,” requires the reactor protection system to initiate automatic action so SAFDLs are not exceeded for conditions that result in unstable power oscillations.

5. GDC 29, “Protection against Anticipated Operational Occurrences,” requires stability LTS design for an extremely high probability of accomplishing safety functions.

6. Generic Letter 94-02 (reference 1) concerns the installation of LTS to satisfy GDCs 10 and 12.

SRP Acceptance Criteria

Specific SRP acceptance criteria acceptable to meet the relevant requirements of the NRC’s regulations identified above are as follows for the review described in this SRP section. The SRP is not a substitute for the NRC’s regulations, and compliance with it is not required. However, an applicant is required to identify differences between the design features, analytical techniques, and procedural measures proposed for its facility and the SRP acceptance criteria and evaluate how the proposed alternatives to the SRP acceptance criteria provide acceptable methods of compliance with the NRC regulations.

1. To meet requirements of GDC 9 the reactor core and its systems should be designed with sufficient margin to be free of undamped oscillations and other thermal-hydraulic instabilities for all conditions of steady-state operation (including single-loop operation and extended-cycle operation with reduced feedwater temperature where these operating conditions are proposed) and for anticipated operational occurrences (AOOs).

2. If potential oscillations cannot be eliminated, design proposals should detect and suppress them reliably and readily.

3. Methodologies for resolving BWR density-wave stability issues are presented in the BWR Owners’ Group topical report NEDO-31960 along with Supplement 1 (References 3 and 4) and were approved by the NRC in Reference 2. These reports provide LTSs to BWR stability issues as well as methodologies developed to support the design of systems needed for plants to comply with GDCs 10 and 12.

4. A reactor is considered stable if it satisfies one of the following criteria:

   A. The calculated decay ratio (DR) for all three common stability modes (core-wide, regional, and channel) satisfies the relationship DR < (1 - σ) where σ is the uncertainty of the calculation. Staff review and approve both the calculation methodology and its uncertainty. The value of σ is typically 0.2 but is methodology-dependent. This value includes the code uncertainty and some degree of variability of the input parameters.

B. Use of an approved correlation to estimate the stability of the regional stability mode based on calculated core-wide and channel DRs is permitted. One example is the FABLE/BYPSS Stability Criteria reviewed and approved by staff and documented in NEDO-31960.

5. An acceptable LTS methodology to satisfy GDC 12 reduces the operating domain by defining an exclusion region where the reactor is not allowed to operate. The exclusion region, defined by the area in the operating map where stability criteria are not met, should be enforced automatically with an approved stability LTS. In addition to the exclusion region, the LTS defines a larger buffer region enforced with administrative controls. The buffer region minimizes challenges to the reactor protection system.

6. An alternative acceptable LTS methodology to satisfy GDC 12 will readily detect and suppress unstable power oscillations by scramming the reactor before SAFDLs are violated. An approved D&S stability LTS should be implemented. SAFDL requirements are specified in SRP Section 4.2, "Fuel System Design," and SRP Section 4.4, "Thermal and Hydraulic Design."

7. Detect and Suppress stability LTSs rely on calculations of the reduction in critical power ratio margin for oscillations of a given amplitude. The response to these D&S LTS hardware oscillations should be modeled by a series of likely oscillation-amplitude contours and randomly failed local power range monitor (LPRM) instruments. Delta CPR over Initial MCPR Versus Oscillation Magnitude (DIVOM) is a staff-reviewed and approved methodology documented in NEDO-32465A.

8. All stability LTS implementations should have backup options in case the licensing solution is declared inoperable. Technical specifications should require that the primary licensing solution be restored in a relatively short period (no longer than 120 days). Backup options in effect for short periods may rely on administrative controls and manual operator actions only if operator actions required to prevent SAFDL exceedences can be reasonably prompt. Backup solution exclusion regions should be confirmed for specific cycles and specified in the core operating limits report (COLR).

9. A number of stability LTSs has been reviewed and approved by the staff. As reactor and fuel designs evolve, the industry may propose new stability LTSs. The following criteria judge the acceptability of new stability LTSs and facilitates meeting the requirements of GDC 20:

   A. The LTS should protect against SAFDL violations automatically.

   B. The LTS should demonstrate by analysis that either (i) the probability of instabilities in the allowed operating region is sufficiently small or (ii) unstable power oscillations can be detected and suppressed readily without SAFDL violations. The LTS may use a combination of both demonstrations for different instability modes.

   C. If the licensing basis option is declared inoperable the LTS should provide a backup option that may implement manual or administrative actions only if operator actions required to prevent SAFDLs can be reasonably prompt.

D. The LTS option should include generic technical specifications that address:

(i) The methodology for setpoint and region calculation and documentation of the setpoint on a cycle-specific basis (e.g., COLR).

(ii) Operability and surveillance requirements for the licensing basis option.

(iii) A time limit (120 days maximum) for operation under the backup option.

10. To meet requirements of GDC 13, stability-related instrumentation functionality should be demonstrated by analysis. Hardware implementation should follow SRP Section 7.2.

11. In addition to the density-wave instability modes, the applicant should ensure that the plant is free from other instability modes that could violate SAFDLs (e.g., startup or control system instabilities) or that oscillations can be detected and suppressed readily. Note: Some instability modes may be acceptable with no potential for SAFDL violation, (e.g., bi-stable flow or small-flow oscillations during low-pressure startup).

Technical Rationale

The technical rationale for application of these requirements to reviewing this SRP section is discussed in the following paragraphs:

1. GDC 12 states, “The reactor core and associated coolant, control, and protection systems shall be designed to assure that power oscillations which can result in conditions exceeding specified acceptable fuel design limits are not possible or can be reliably and readily detected and suppressed.” GDC 12, therefore, sets two types of generic LTS requirements: (A) exclusion region solutions that reduce the operating domain by defining an exclusion region where the reactor is not allowed to operate and (B) D&S solutions that scram the reactor if oscillations develop.

2. For plants with D&S solutions, unstable power oscillations are AOOs. GDC 20 requires effective reactor protection system protection against SAFDLs for AOOs. Thus, the success criteria for protection system actuation during unstable power oscillations are avoidance of boiling transition and other criteria specified in SRP Sections 4.2 and 4.4 even though during short events fuel damage may not occur.

3. The LTS protection should be automatic. Manual and administrative actions are acceptable as backup systems when the primary licensed LTS is declared inoperable for a period of up to 120 days. Manual actions are acceptable for a short time if only a small probability of an instability that would challenge SAFDLs can be shown in reasonable operator action times. If this small probability cannot be demonstrated, there should be an automatic backup. For example, in operations at MELLLA+ conditions, calculations show that large unstable power oscillations may develop rapidly and violate SAFDL within approximately one minute following a recirculation pump trip. An automatic backup system is required in this situation.

4. For instability modes other than density-wave stability, a third option is provided for acceptance if these instability modes have no potential to violate SAFDLs. The criteria in this SRP specify that the intent of GDC 12 is that the reactor may be designed and continue to operate in the presence of any such oscillations if they have no potential of violating SAFDLs.

5. There is a third acceptance option for instability modes other than density-wave stability. Criteria in this SRP specify that the GDC 12 intent is that the reactor may be designed to operate with any such oscillations if they cannot violate SAFDLs.

III. REVIEW PROCEDURES

The reviewer will select material from the procedures described below, as may be appropriate for a particular case.

For each area of review specified in subsection I of this SRP section, the review procedure is identified below. These review procedures are based on the identified SRP acceptance criteria. For deviations from these specific acceptance criteria, the staff should review the applicant's evaluation of how the proposed alternatives to the SRP criteria provide an acceptable method of complying with the relevant NRC requirements identified in subsection II.

Portions of the review may be done generically for aspects common to a class of plant designs or by adoption of the results of previous reviews of plants of similar design. The areas for attention and emphasis are based on whether the information in the applicant's safety analysis report (SAR) is similar to that reviewed for other similar plant designs, whether it refers to previously accepted evaluations and/or nuclear steam supply system vendor topical reports, whether it proposes new or unique features affecting the stability risk, and whether the areas involve items of special safety significance.

The evaluation of compliance with acceptance criteria may be based on referenced approved designs, analyses, and/or assessments including topical reports, standard design approvals, and designs of systems previously reviewed and approved by the staff. If there is any aspect of a design not identical to the referenced design, an evaluation should address the differences and the conclusions on such differences should be included in the safety evaluation report (SER).

The reviewer evaluates the applicant's SAR information on thermal-hydraulic stability concerns during normal operations and anticipated operational occurrences for compliance with specific acceptance criteria listed in subsection II of this SRP section. Specifically:

1. The reviewer verifies whether the reactor and its systems facilitate automatic protective action either to prevent thermal-hydraulic instabilities or to make certain that specified acceptable fuel design limits are not exceeded in thermal hydraulic instabilities in accordance with the recommendations of topical reports NEDO-31960 and NEDO-31960, Supplement 1, as approved by the related SER (Reference 2) or other approved LTS methodologies.

2. The reviewer verifies whether the reactor and its subsystems are free from instabilities other than density-wave instability (*e.g.*, startup or control system instabilities) or whether those instability modes have insignificant effects on SAFDLs.

3. The reviewer verifies whether technical specifications satisfy acceptance criteria listed in subsection II of this SRP section.

4. The reviewer verifies whether all analysis methodologies including treatment of uncertainties in the submission have been reviewed and approved by staff.

5. The reviewer evaluates the need for staff-confirming calculations if design changes deviate significantly from established practice.

6. For review of a DC application, the reviewer should follow the above procedures to verify that the design, including requirements and restrictions (e.g., interface requirements and site parameters), set forth in the final safety analysis report (FSAR) meets the acceptance criteria. DCs have referred to the FSAR as the design control document (DCD). The reviewer should also consider the appropriateness of identified COL action items. The reviewer may identify additional COL action items; however, to ensure these COL action items are addressed during a COL application, they should be added to the DC FSAR.

   For review of a COL application, the scope of the review is dependent on whether the COL applicant references a DC, an early site permit (ESP) or other NRC approvals (e.g., manufacturing license, site suitability report or topical report).

IV. EVALUATION FINDINGS

The reviewer verifies that the applicant has provided sufficient information and that the review and calculations (if applicable) support conclusions of the following type to be included in the staff's SER. The reviewer also states the bases for those conclusions.

The staff concludes that the plant design adequately addresses stability issues and satisfies GDCs 10, 12, 13, 20, and 29, Appendix A, 10 CFR Part 50, and Generic Letter 94-02. This conclusion is based on the following findings:

1. The applicant’s plant design includes a stability LTS implementation that either prevents density-wave instabilities or can readily detect and suppress the oscillations.

2. The applicant has provided or referred to information and/or analyses that demonstrate that the plant design is free of other instability modes or that such instability modes cannot violate SAFDLs.

3. All calculation methodologies and referenced information have been reviewed and previously approved by the staff.

4. The applicant has provided technical specifications that address the stability LTS implementation, including setpoint generation, surveillance, and operability requirements. Setpoints and exclusion regions, if applicable, are defined in the COLR.

5. Hardware implementation of the LTS has been reviewed and satisfies in SRP Section 7.2.

For DC and COL reviews, the findings will also summarize (to the extent that the review is not discussed in other SER sections) the staff's evaluation of the ITAAC, including design acceptance criteria, as applicable, and interface requirements and combined license action items relevant to this SRP section.

V. IMPLEMENTATION

The staff will use this SRP section in performing safety evaluations of DC applications and license applications submitted by applicants pursuant to 10 CFR Part 50 or 10 CFR Part 52. Except when the applicant proposes an acceptable alternative method for complying with specified portions of the Commission's regulations, the staff will use the method described herein to evaluate conformance with Commission regulations.

The provisions of this SRP section apply to reviews of applications docketed six months or more after the date of issuance of this SRP section, unless superseded by a later revision.

VI. REFERENCES

1. Generic Letter 94-02, "Long-Term Solutions and Upgrade of Interim Operating Recommendations for Thermal-Hydraulic Instabilities in Boiling Water Reactors," March 5, 1996.

2. A. C. Thadani, "Acceptance for Referencing of Topical Reports NEDO-31960 and NEDO-31960 Supplement 1, BWR Owners Group Long-Term Stability Solutions Licensing Methodology," U.S. Nuclear Regulatory Commission, July 12, 1993.

3. NEDO-31960, "BWR Owners Group Long-Term Stability Solutions Licensing Methodology," General Electric Company, May 1991.

4. NEDO-31960 Supplement 1, "BWR Owners Group Long-Term Stability Solutions Licensing Methodology," General Electric Company, March 1992.

5. NEDO-32465A, "BWR Owners Group Reactor Stability Detect and Suppress Solutions Licensing Basis Methodology for Reload Applications," GE Nuclear Energy, August 1996.

6. NEDC-33075P, Revision 5, "General Electric Boiling Water Reactor Detect and Suppress Solution-Confirmation Density," GE Nuclear Energy, November 2005.

SRP Section 15.9
Description of Changes

This SRP section affirms the technical accuracy and adequacy of the guidance previously provided in Draft Revision 0 of this SRP section.

In addition, this SRP section was administratively updated in accordance with NRR Office Instruction LIC-200, Revision 1, "Standard Review Plan (SRP) Process." The revision also adds standard paragraphs to extend application of this updated SRP section to prospective applicant submissions pursuant to 10 CFR Part 52.